GPS/GNSS and Space Weather - Commercial Perspective

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Founder, CEO, Chief Scientist

& ASTRA Science/Engineering Team

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ASTRA: Overview

❖Science
❖ Technology
❖ Applications
Bringing It All Together

ASTRA

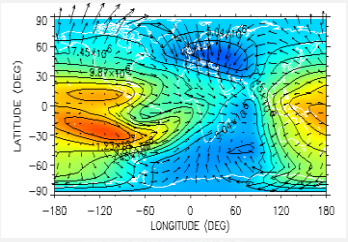
- **Small business specializing in space environment modeling/prediction and space technology development**
- **The vibrancy of Small Businesses is driving the US economy**

Hiring Engineers and Scientists!

Core Competencies

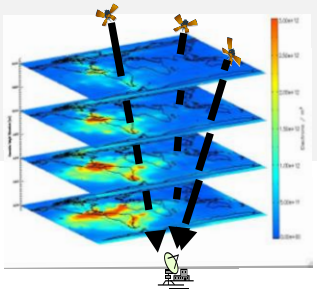
Numerical Modeling

- Physics-Based Modeling
- Real-Time Specification



Data Assimilation

- Ionospheric Electron Density
- Thermospheric Neutral Density
- High-Latitude Electrodynamics

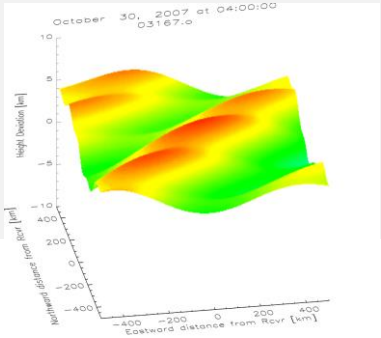


Data Services

- Satellite and Ground Sensors
- Time-Frequency Analysis
- Wavelet Analysis

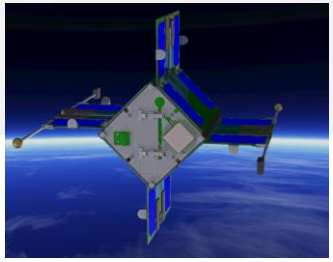
Instrument Development

- GPS TEC/Scint
- HF TID Mapper
- Low Power Ionosonde



Space Systems

- DICE Cubesat
- DIME Cubesat
- SENSE Cubesat
- UV Sensor
- E-field Sensor
- Topside Sounder



Society Depends on GPS

❖Science
❖ Technology
❖ Applications
Bringing It All Together

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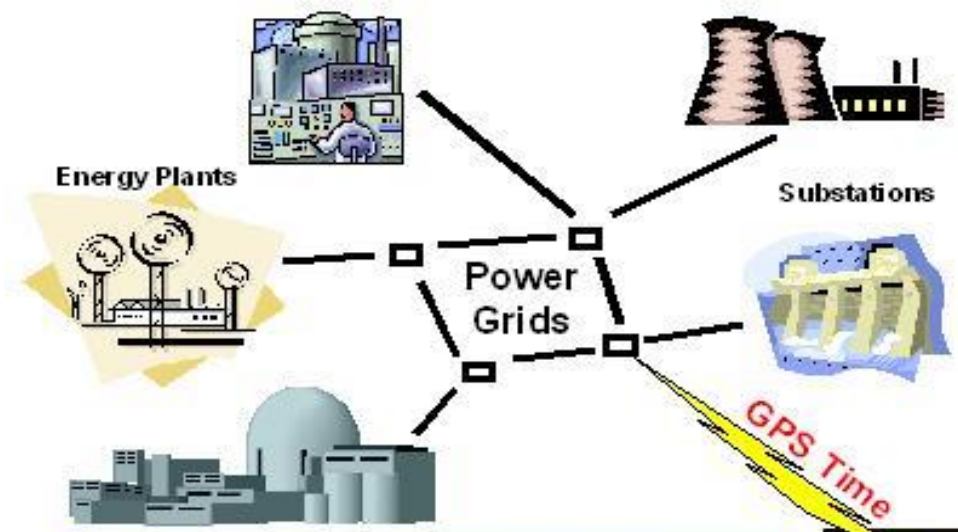
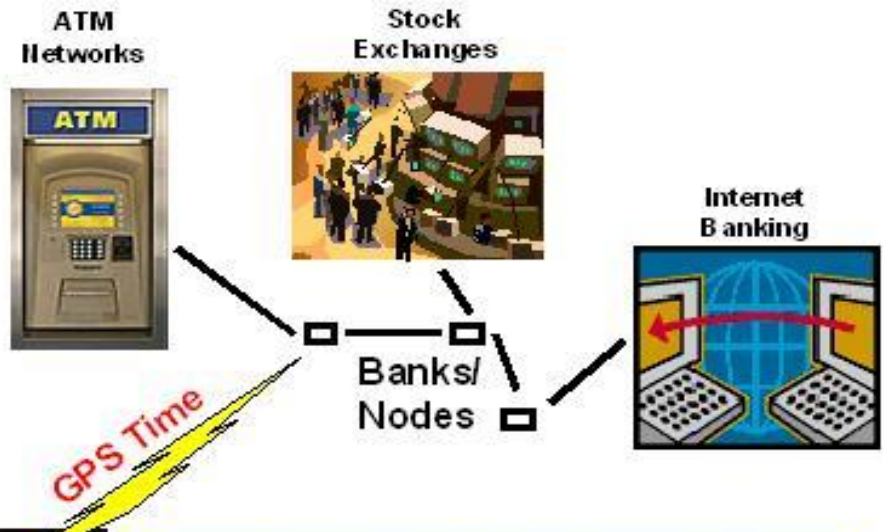
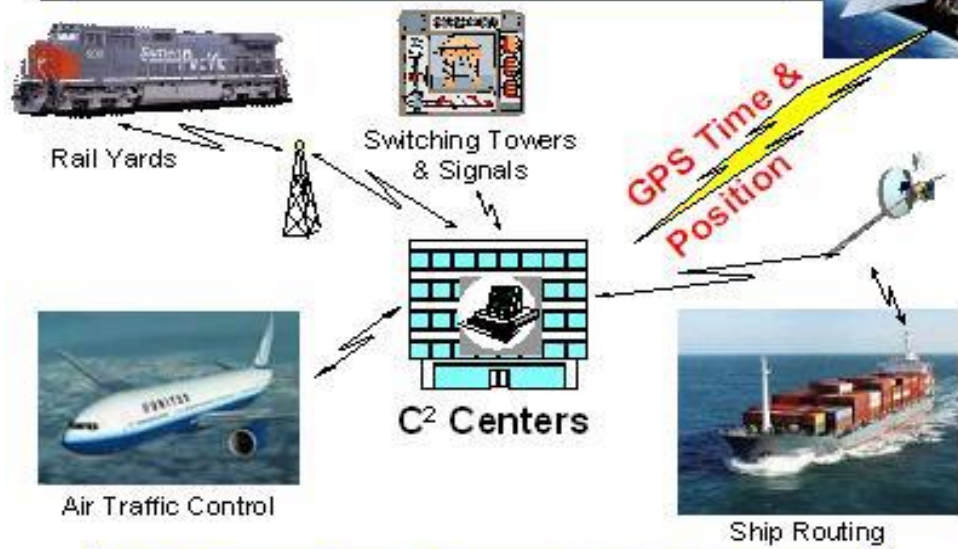
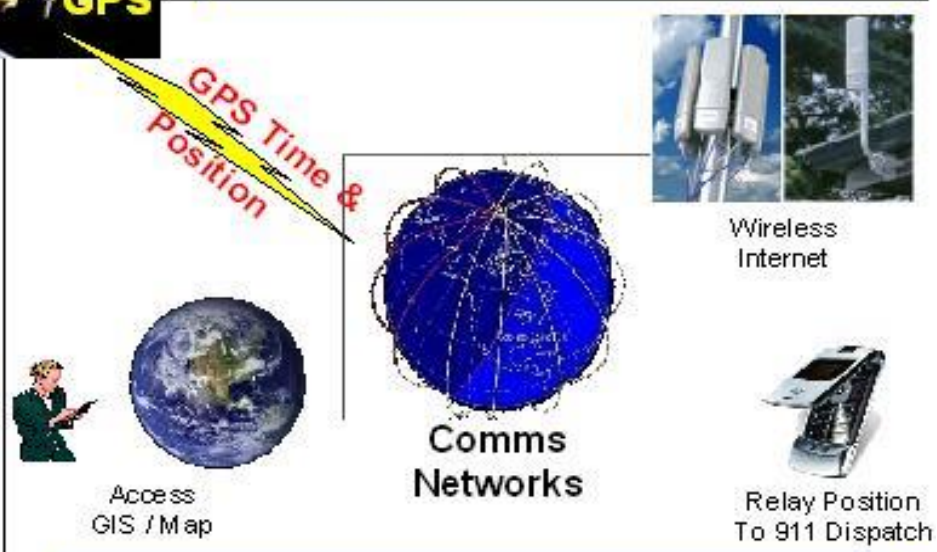


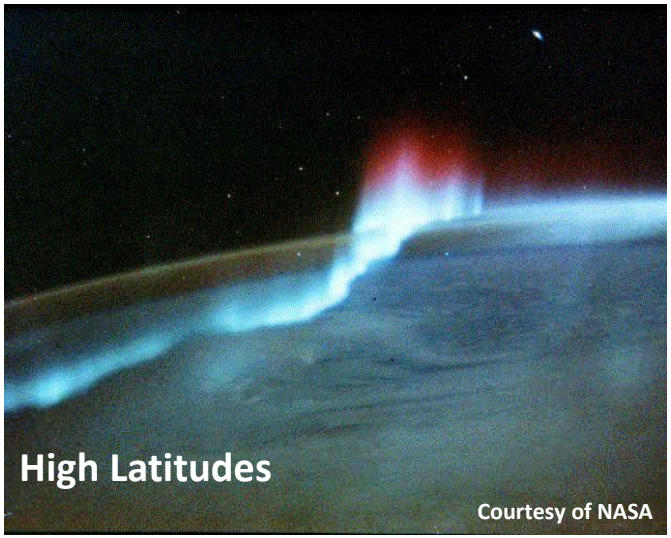


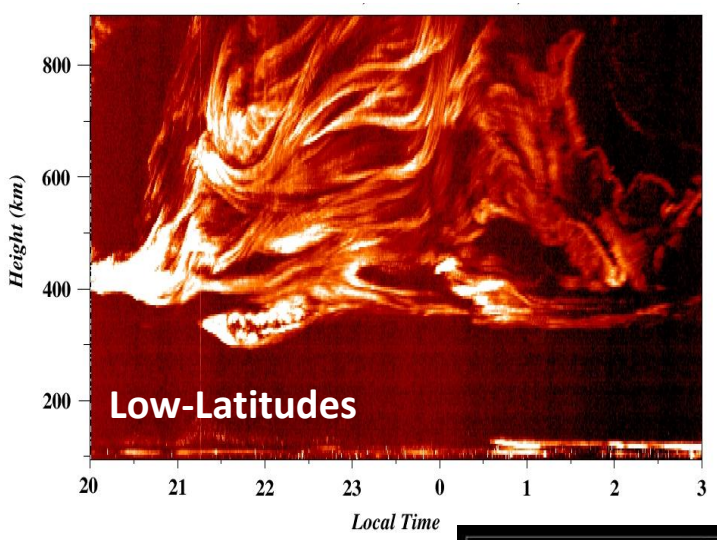


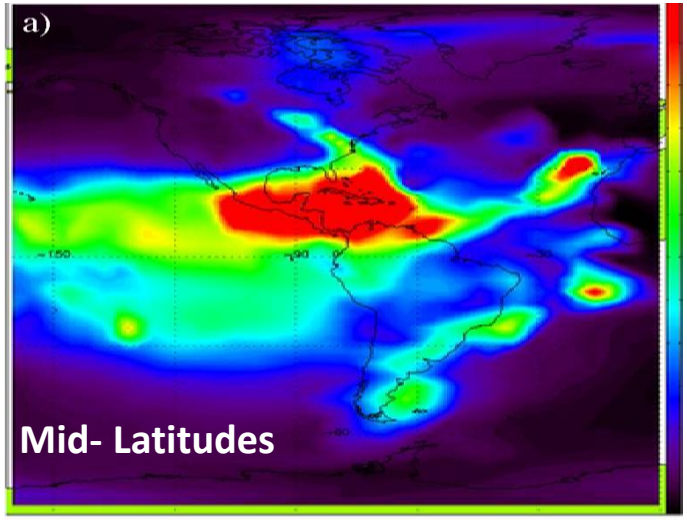


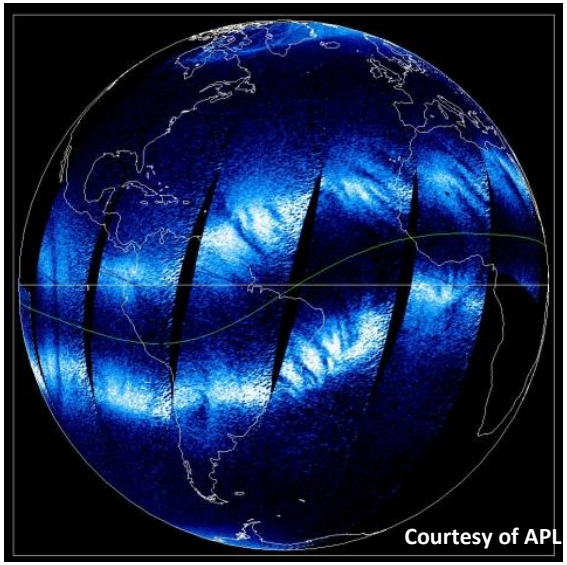
Ionospheric Space Weather

High latitude and low latitude ionospheric effects are different and distinct

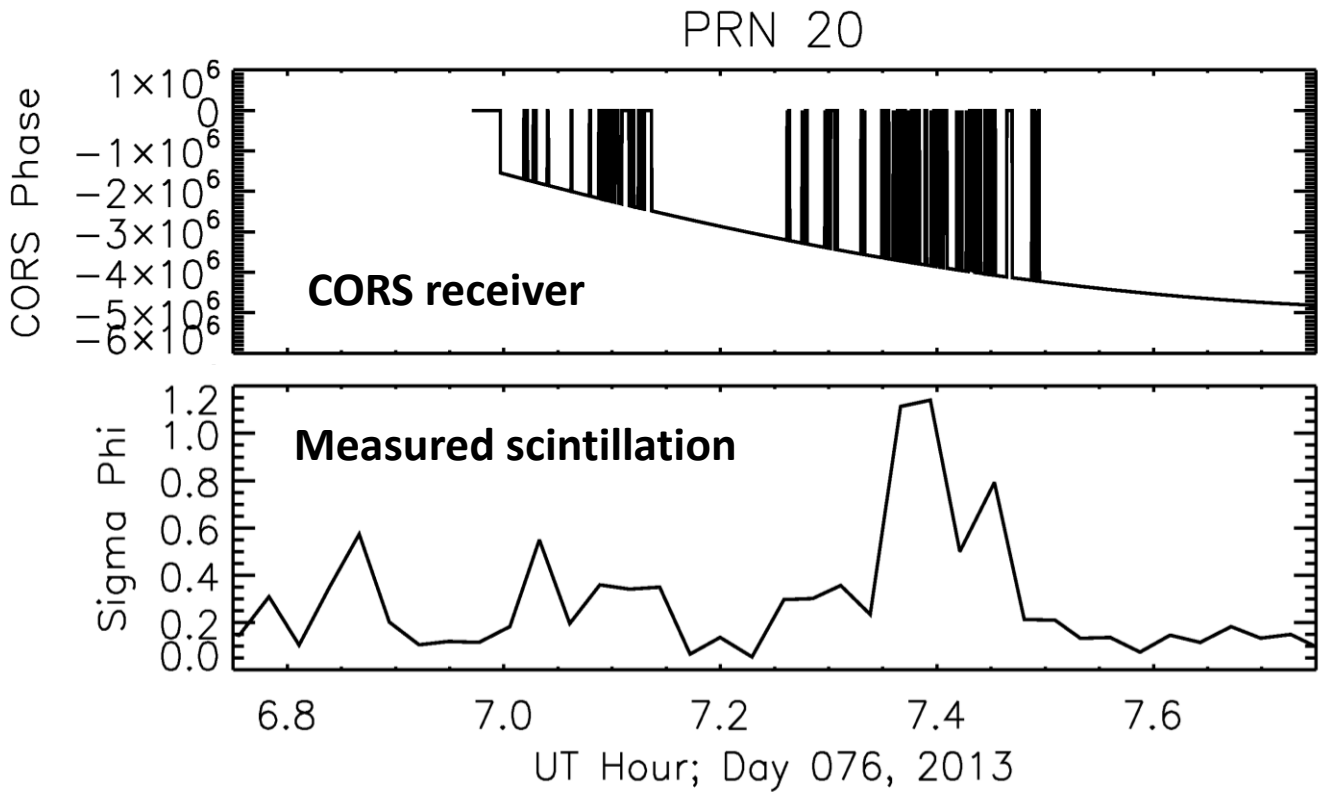




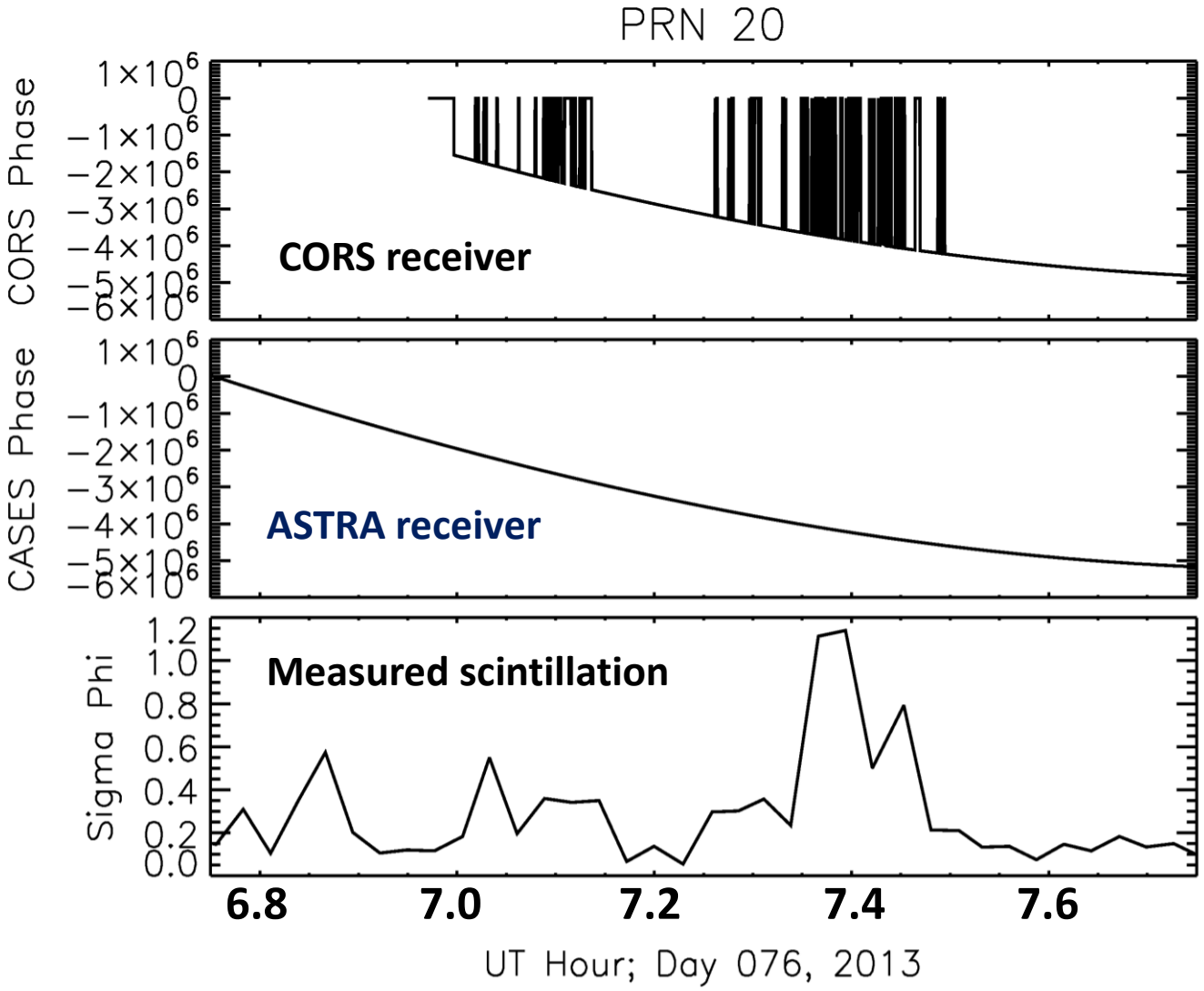




Ionospheric Effects

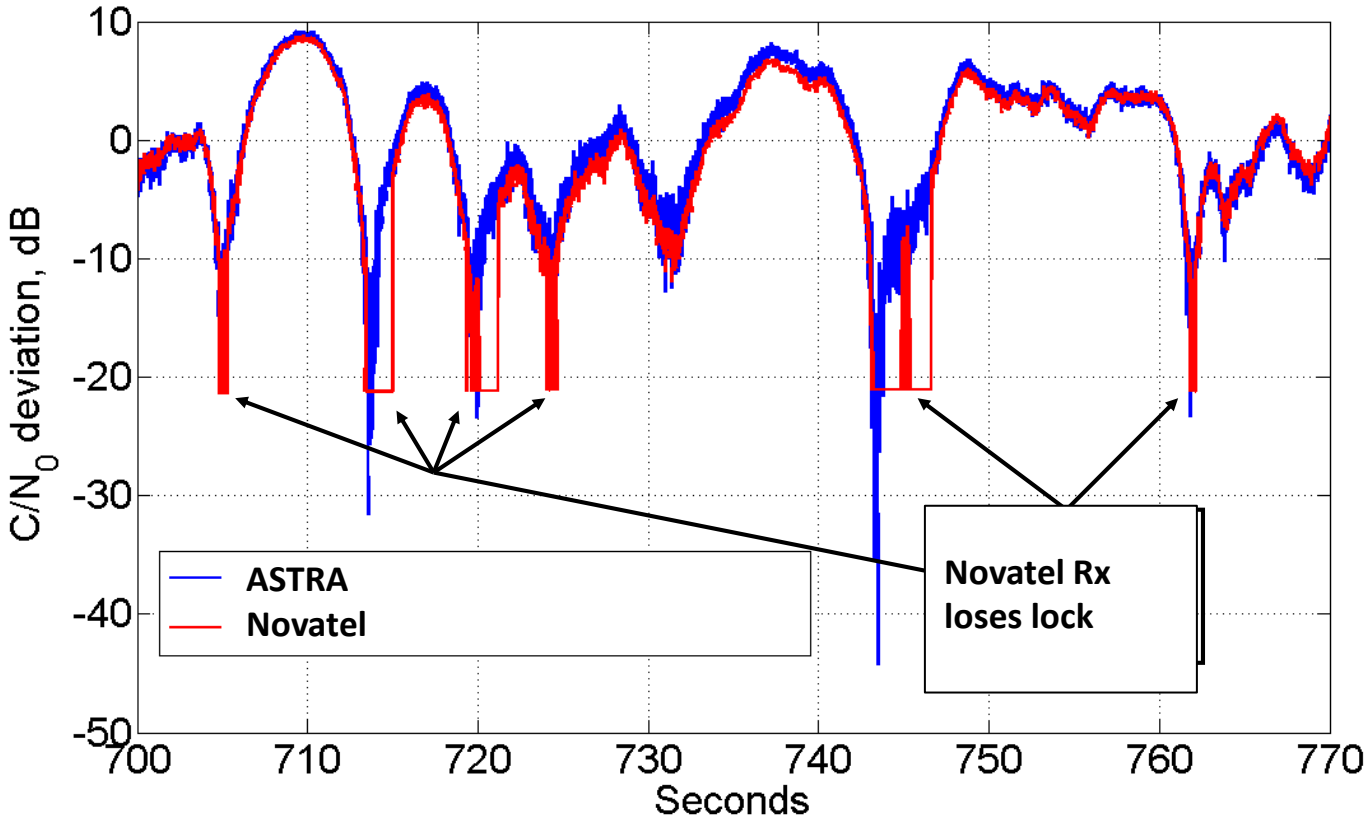


Ionospheric Effects



Air Force funded ASTRA/Cornell to develop a GPS receiver to track through scintillation

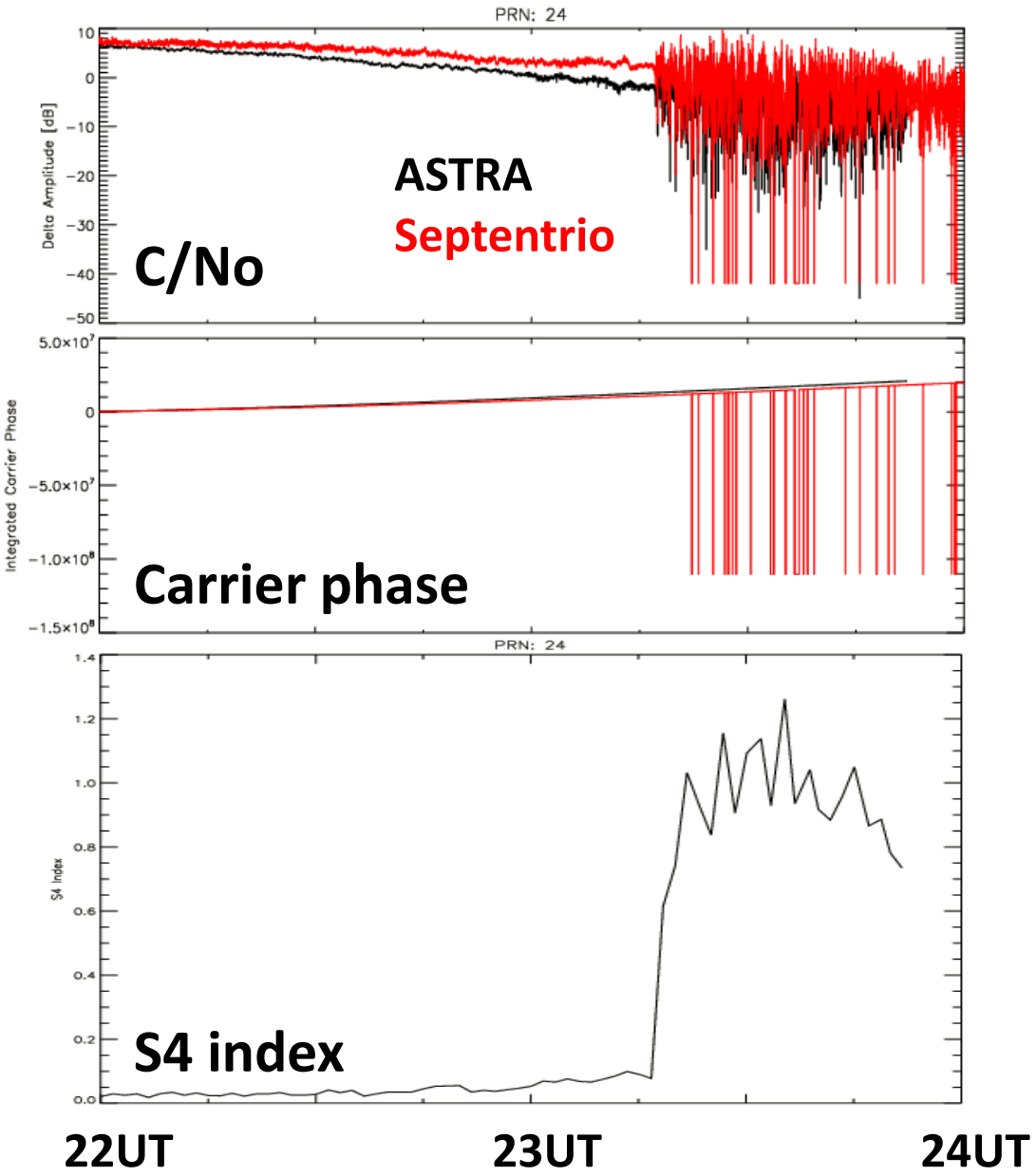
ASTRA vs Novatel Receiver



The CASES specialized tracking loop (blue trace) allows robust tracking during scintillations versus other receivers using fixed bandwidth PLL (red trace) which lose lock.

Data collected from Jicamarca, Peru at magnetic equator.

ASTRA vs Septentrio PolaRxS



Data collected in Brazil

Tracking Loops Performance

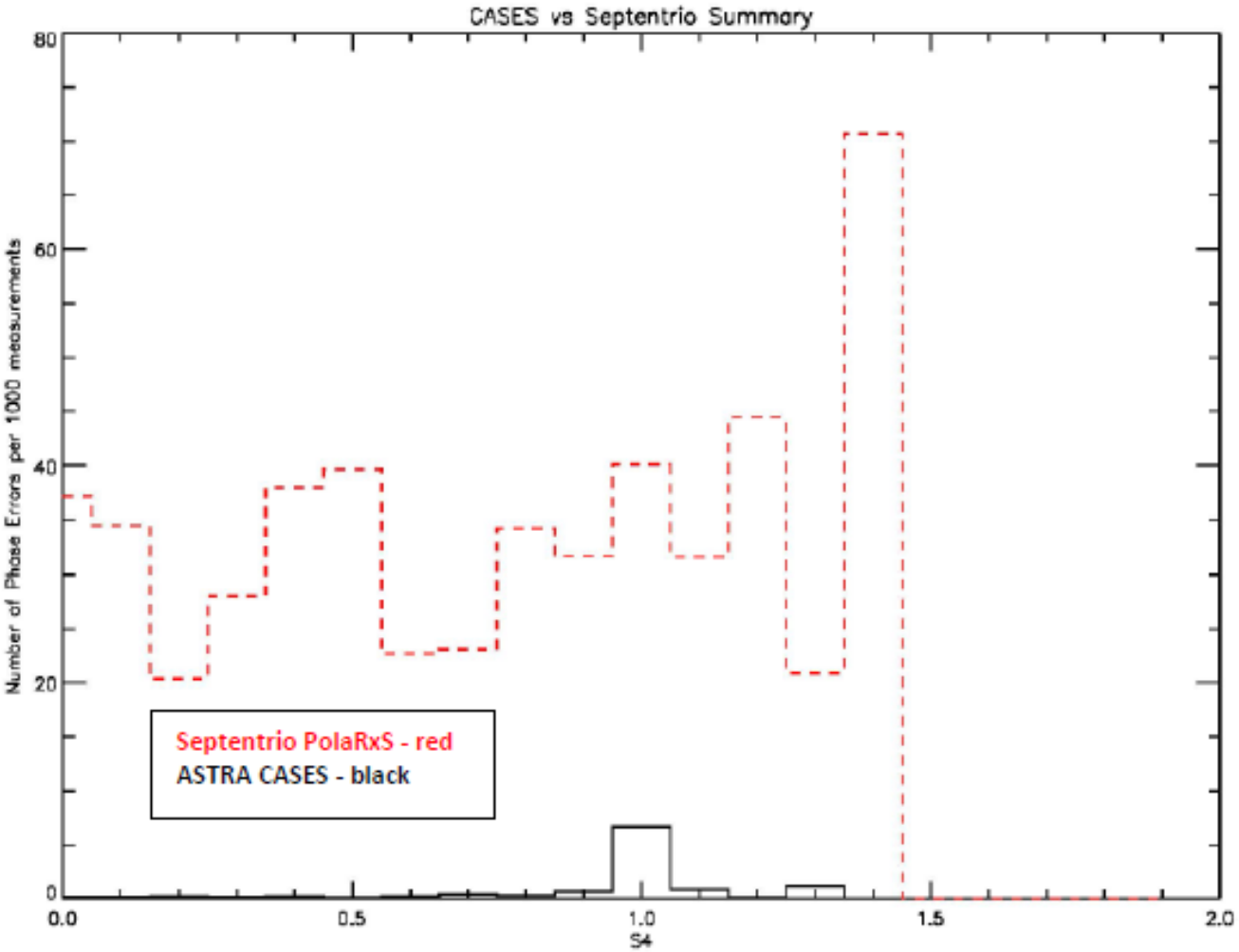


Figure A-2. Number of Phase Errors per 1000 measurements vs. Amplitude scintillation index (S4) demonstrating the tracking performances of the CASES and PolaRxS receivers over six month period.

ASTRA GPS Receiver

❖Science
❖ Technology
❖ Applications
Bringing It All Together

ASTRA

- **Superior performance in scintillation**
- **Standalone system (*internal computer*)**
- **Low power (2.5W)**
- **Cost-effective instrument**
- **Made in the USA**
- **Remote re-programmability**
- **Full control of receiver behavior, products**
- ***Good educational tool (Scales et al., VaTech)***

Dual frequency (L1 and L2C)
GAMMA GPS Receiver

Data Type	Per Channel High Rate Data	Per Channel Low Rate Data	Per Channel Scint Params	Other
Default Data Rate	**100 Hz**	**1 Second**	**60 Seconds**	**1 Second**
Configurable Rate?	Yes, 50 or 100 Hz	Yes, >= 1 Second	Yes	Yes, >= 1 Second
Available Parameters	• Integrated Carrier Phase • In-Phase Accumulation • Quadrature Accumulation • GPS Time • Receiver Time	• Pseudorange-based **TEC** • Phase-based delta **TEC** • Pseudorange • Integrated Carrier Phase • GPS Time, Receiver Time • Doppler Frequency • SV Elevation, SV Azimuth • C/N0 • Data Validity Flag, Cycle Slip Flag • Signal Acquisition Status • PRN, SV Health	• S_4 • σ_φ • τ_o • Scint Power Ratio • GPS Time • Reference Channel Status • PRN	• Receiver X/Y/Z Position • Receiver X/Y/Z GPS Time • Receiver Time • Velocity • Receiver Clock Error • Receiver Clock Error Rate • Nav Solution Flag

ASTRA: GPS Heritage Since 2008

❖Science
❖Technology
❖ Applications
Bringing It All Together

ASTRA

Reduced size, weight, and power

CASES (2009)
2nd Generation

CASES SM-211
(2011)
3rd Generation

CASES Antarctic
(2013)
4th Generation

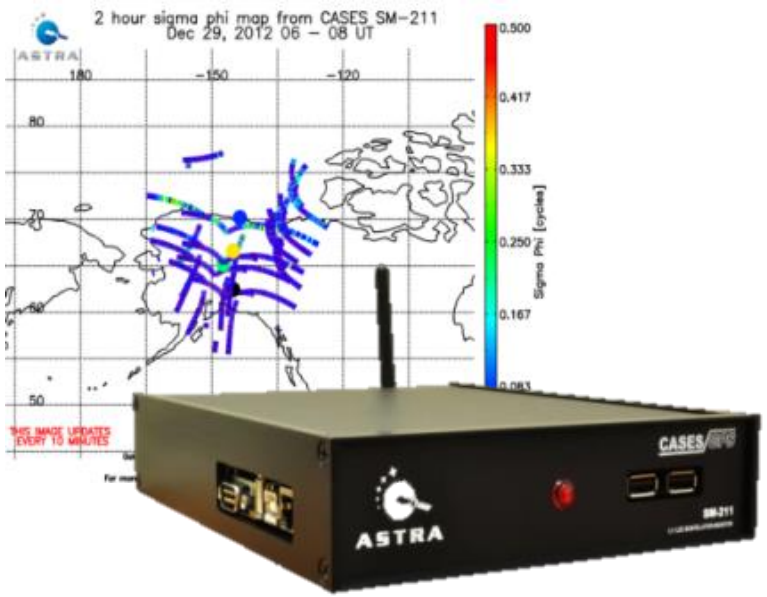
GAMMA (2014)
5th Generation

Development funded by AFRL via SBIR Program

Realtime Scintillation Monitoring

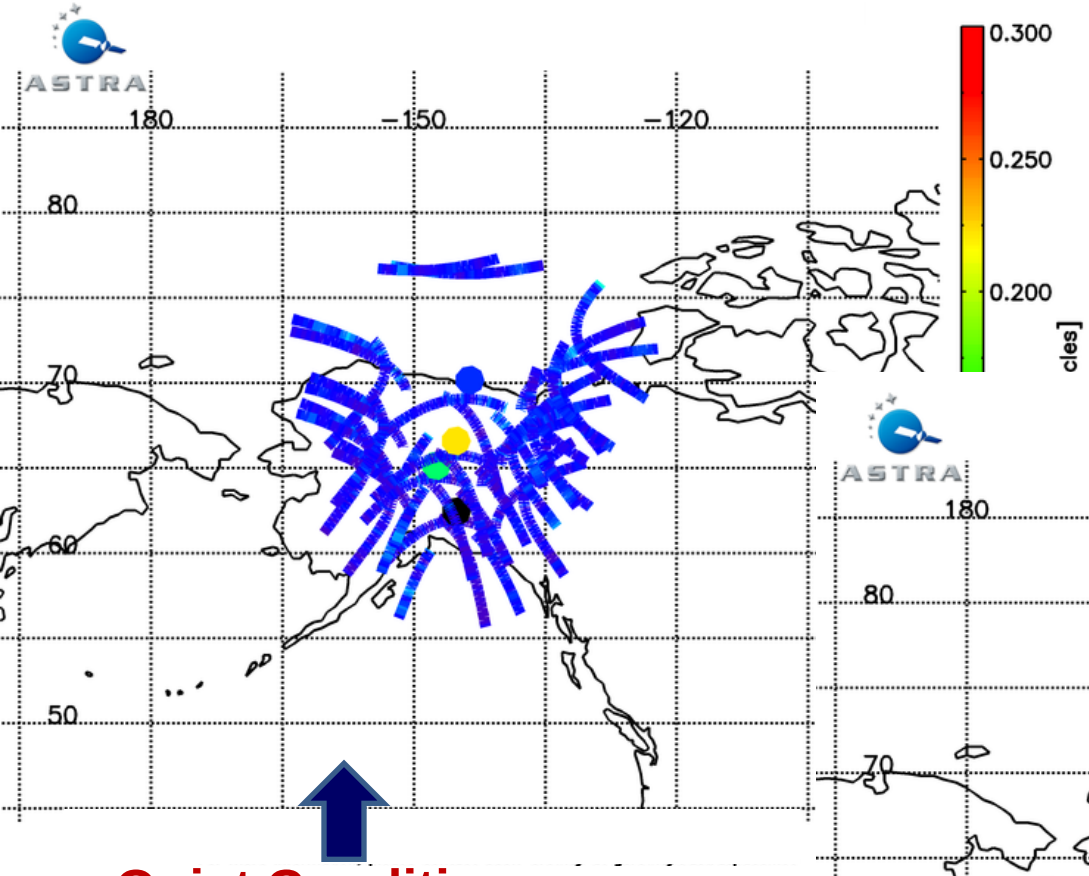
Array of CASES receivers deployed in Alaska:

- Kaktovik (70.1° N, 143.6° W)
- Toolik (68.6° N, 149.6° W)
- Fort Yukon (66.6° N, 145.2° W)
- Poker Flat (65.1° N, 147.4° W)
- Eagle (64.8° N, 141.2° W)
- Gakona (62.4° N, 145.2° W)

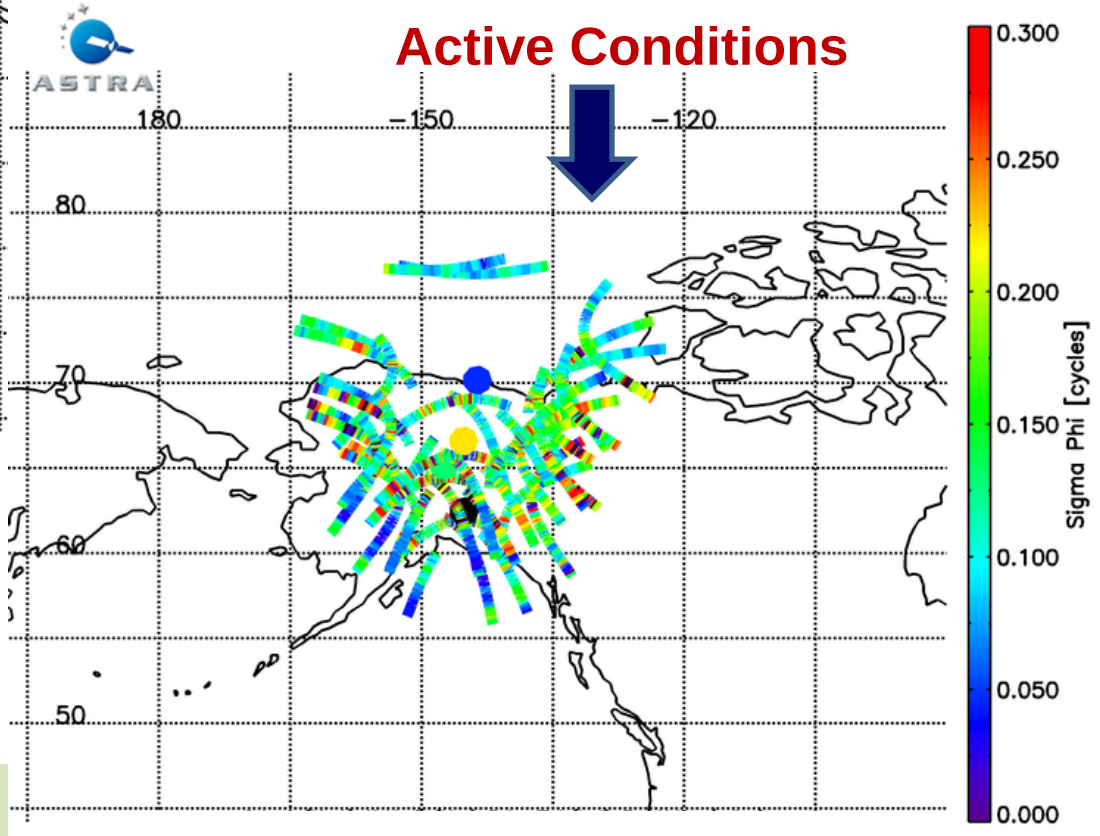


Unattended operation in remote locations since 2012

Realtime Scintillation Monitoring



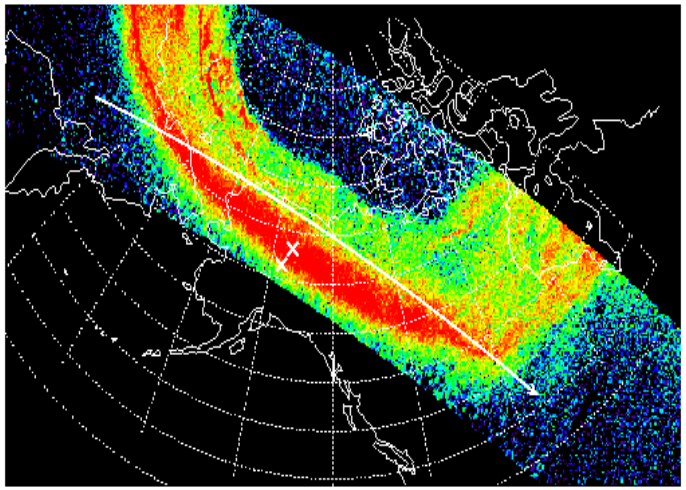
Quiet Conditions



Active Conditions

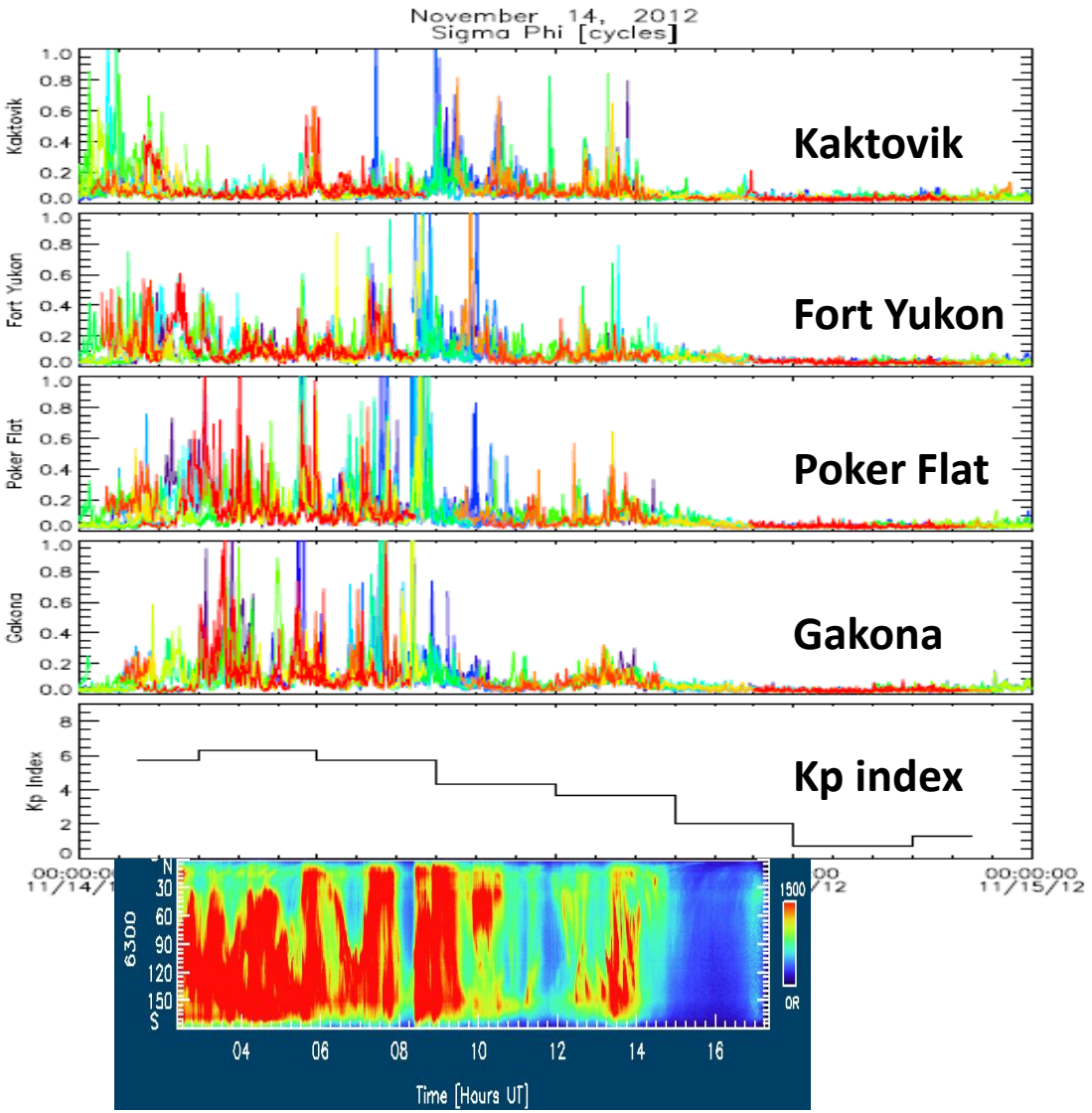
http://cases.astraspace.net

Realtime Scintillation Monitoring



Aurora over Alaska every night

ASTRA 'CASES' Receiver



See Poster I-25, Loucks et al.

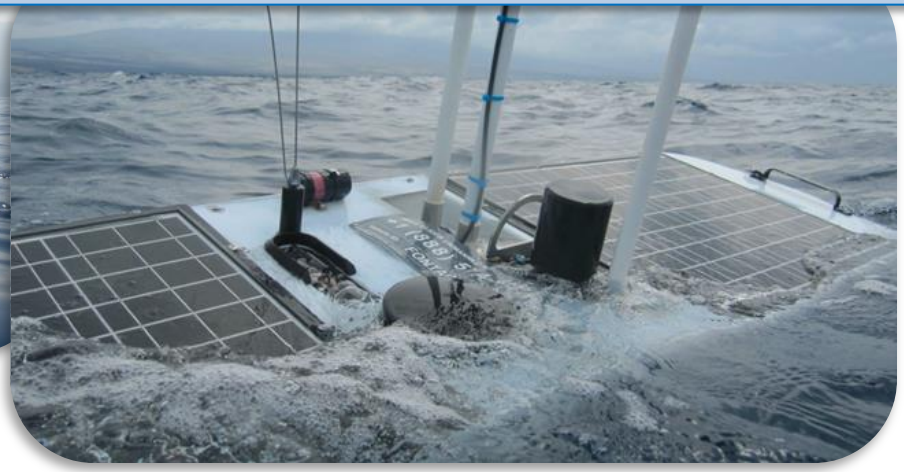
Ionospheric Monitoring from Moving Platforms

❖ Science
❖ Technology
❖ Applications
Bringing It All Together

ASTRA

"No one else in the World has done this…"

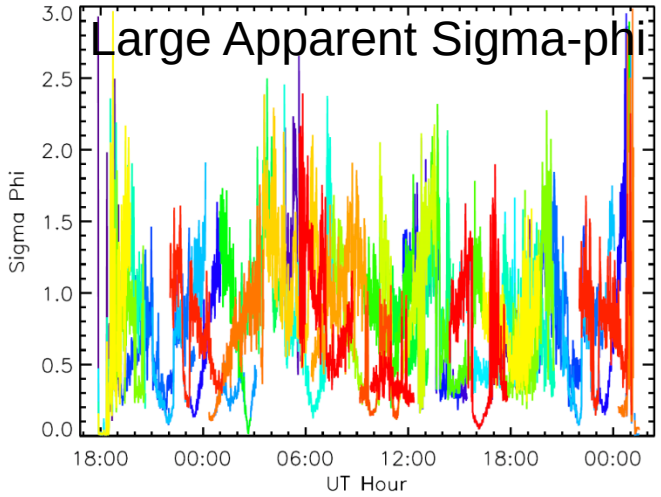
– recent quote from Technical Director of a multi-Billion dollar International Commercial Services company that provides marine data services



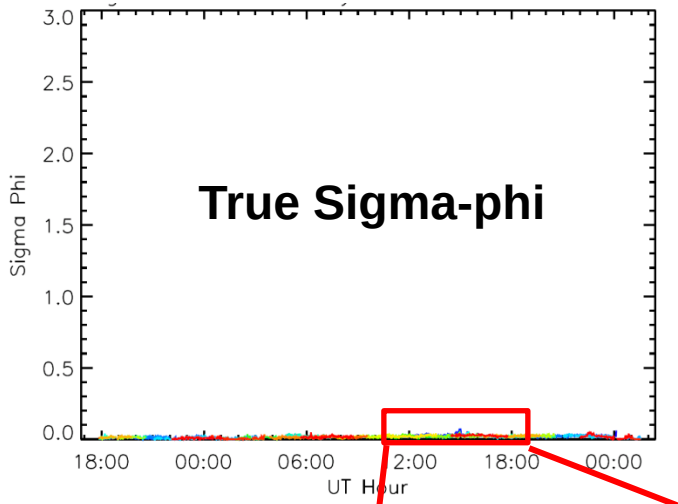
- Near real-time ionospheric data from moving platform
- Patented technique
- Data Products: TEC, scintillation data products, and system status
- Ground link via Iridium or cell towers
- Programmable data latency (Nominal 5 minutes)

Validation of Motion Removal Against Land-based Receivers

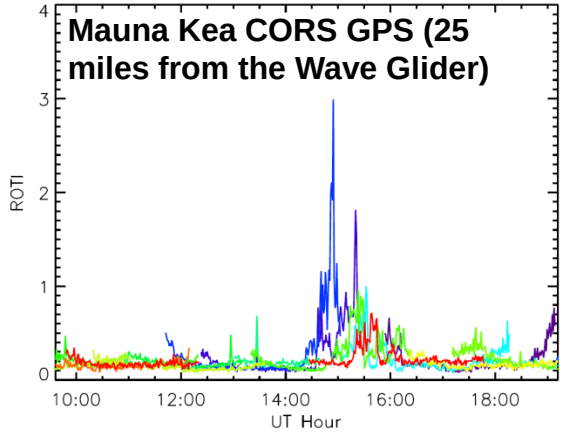
Without Motion Correction



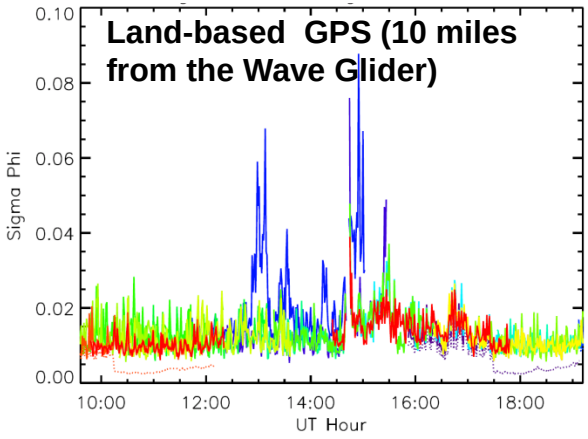
With Motion Correction



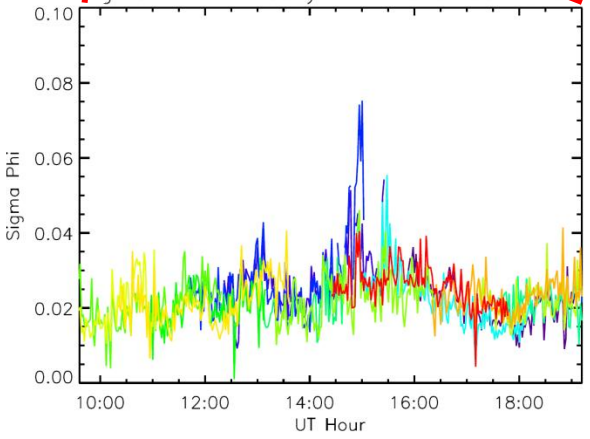
MKEA ROTI



Sigma_phi from nearby ASTRA Rx



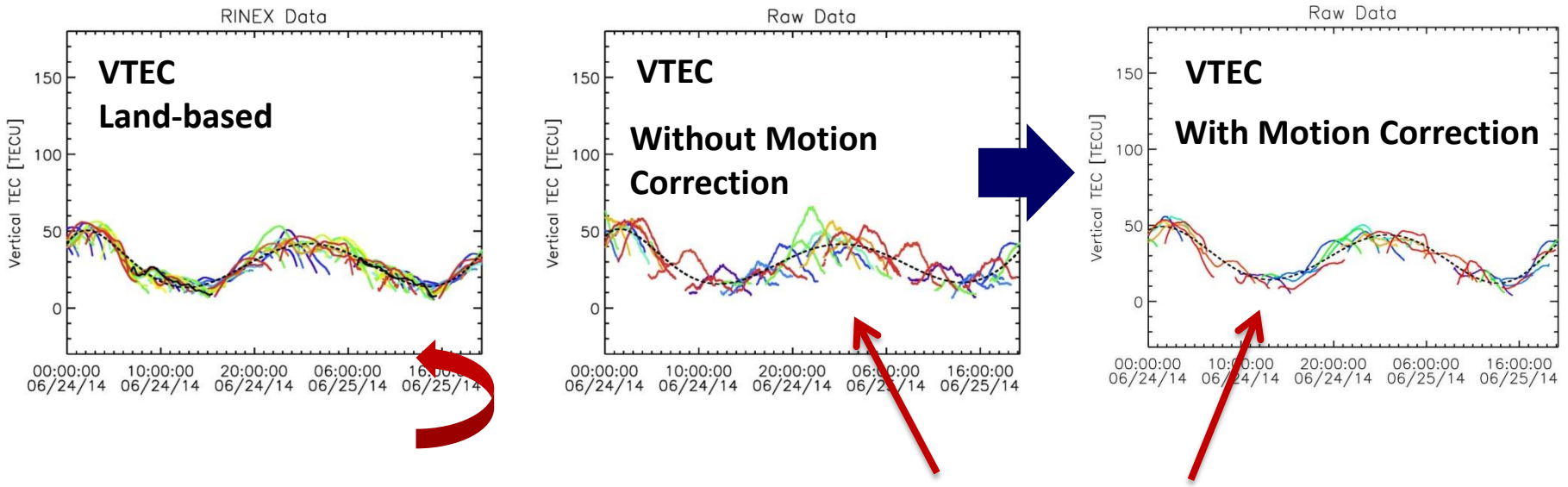
With Motion Correction



VTEC from a Buoy (Hawaii)

Land Based Measurement:
Mauna Kea CORS GPS (25 miles from the Wave Glider)

GAMMA GPS receiver on the ocean

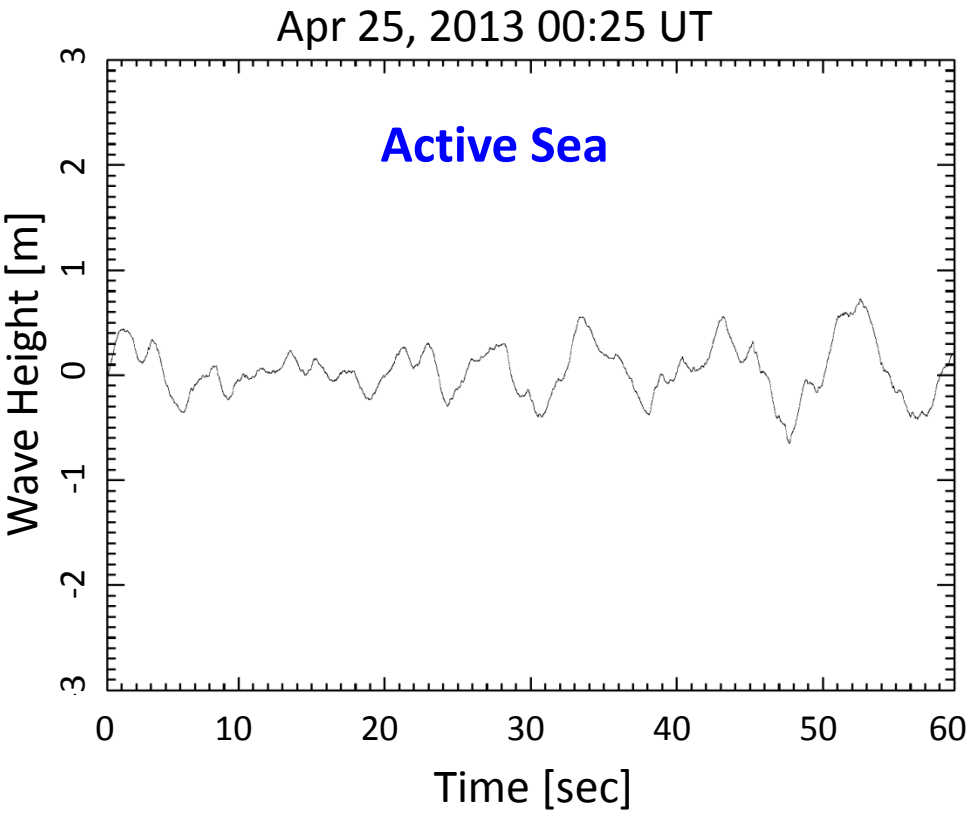


Vertical TEC from the CORS receiver at Mauna Kea.

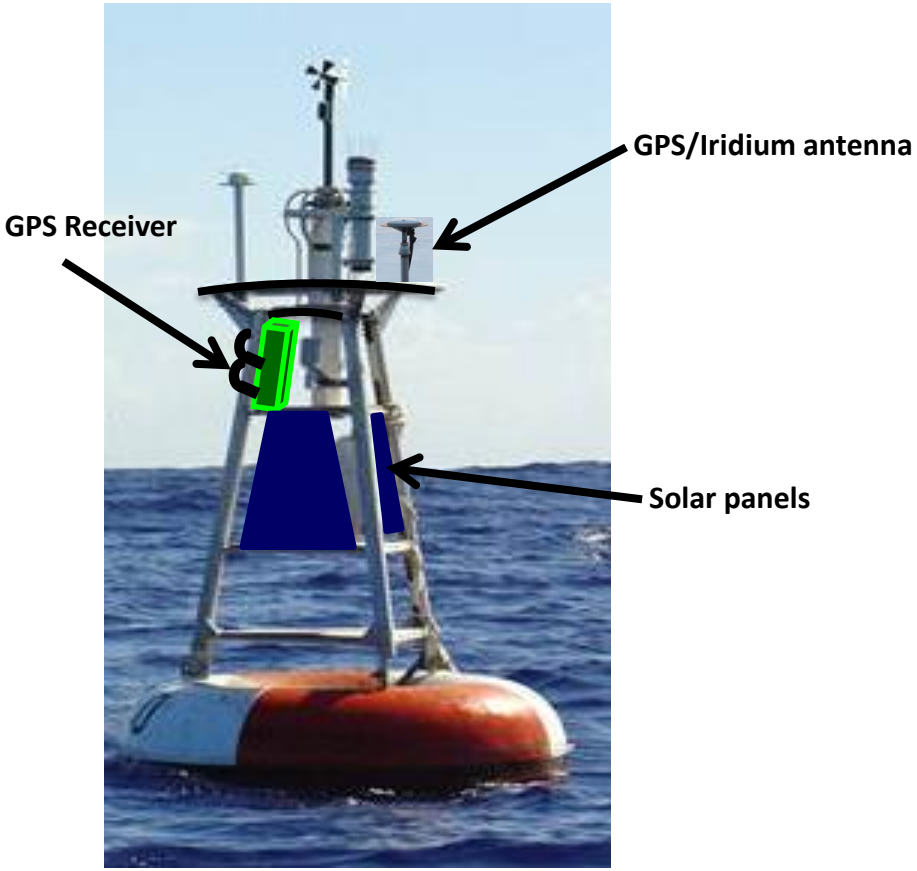
Vertical TEC from GAMMA on the Wave Glider.

- Accurate TEC measurements are critical for extraction of TID signals.
- GAMMA GPS receiver provides accurate TEC measurements enabling TID characterization from moving platforms

Wave Height Algorithm



Installation on NOAA Buoys



Any Moving Platform!

NASA DC-8 (over 50 flights)

Navy Twin Otter (several flights)

R2O and O2R in GPS Receivers

❖Science
❖ Technology
❖ Applications
Bringing It All Together

ASTRA

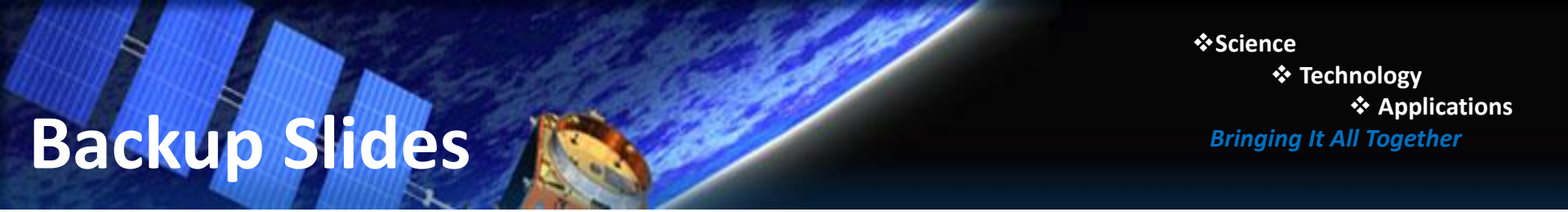
Customer-driven Development

CASES (2009)	**CASES SM-211** (2011)	**CASES Antarctic** (2013)	**GAMMA** (2014)
2nd Generation	**3rd Generation**	**4th Generation**	**5th Generation**
(TRL-1) TRL-4	TRL-8	TRL-8	TRL-9
15W	7.5 W (lower voltage)	Form-factor	2.5 W (components)
Prototype	Commercial Quality		Better computer
			Motion removal
			Commercial Quality

SUMMARY

- **GPS/GNSS is ubiquitous in society**
- **Space Weather can disrupt or deny GPS service**
- **Loss or disruption of GPS can be important to operations**
- **Air Force funded development of scintillation/TEC monitor**
  - ✓ Tracks through scintillation
  - ✓ Low Power
  - ✓ Low cost
  - ✓ *Made in USA*
  - ✓ On-board computer

  R2O and O2R
- **Reliable operation on moving platforms**
- **Suitable for monitoring Space Weather conditions**
- **Detects scintillation affecting operational systems**
- **SBIR product, so it can be sole-sourced**
- **Educational applications**
- **Many commercial applications (e.g. arrays, single site)**



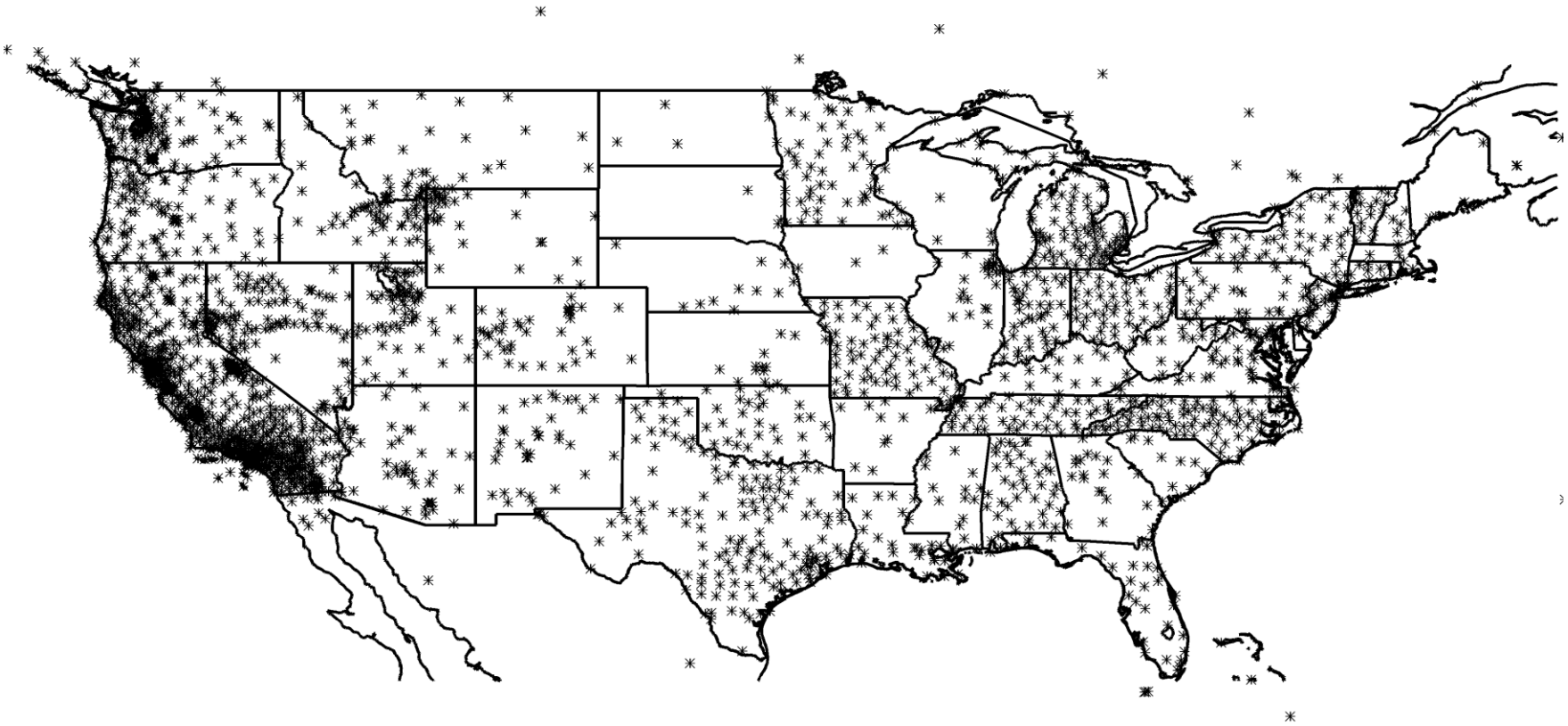
Backup Slides

❖Science
❖ Technology
❖ Applications
Bringing It All Together

GPS-Derived Traveling Ionospheric Disturbances (TIDs)

❖Science
❖ Technology
❖ Applications
Bringing It All Together

- **ASTRA is using CORS and other GPS data for analysis of TIDs**
- **~3,800 GPS receivers in the US**
- **10-100 km horizontal spacing**
- **30-sec sampling (decimated)**



TID Examples from GPS TEC

❖Science
❖Technology
❖ Applications
Bringing It All Together

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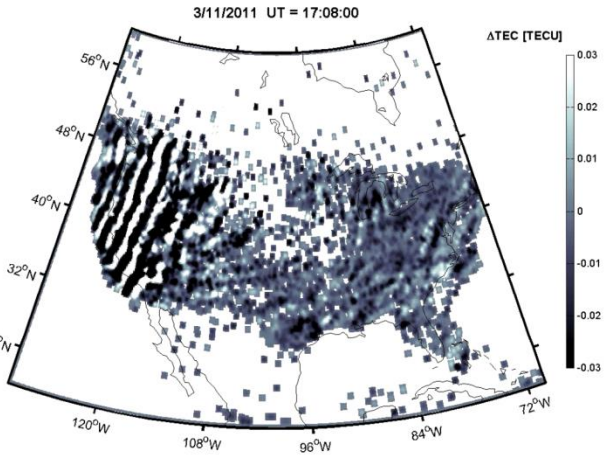
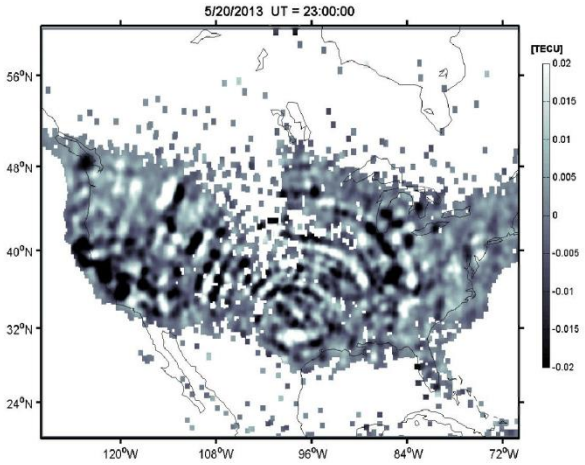
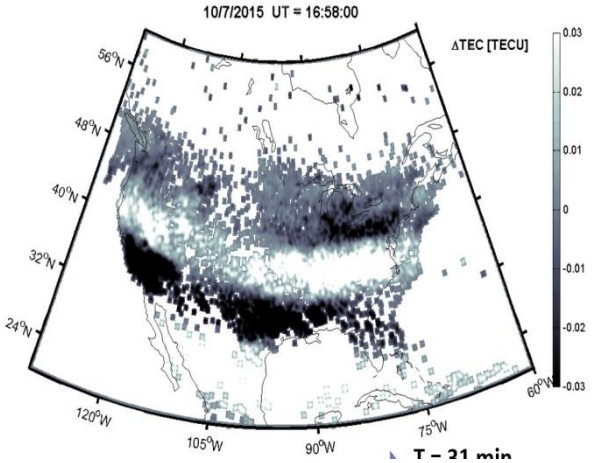
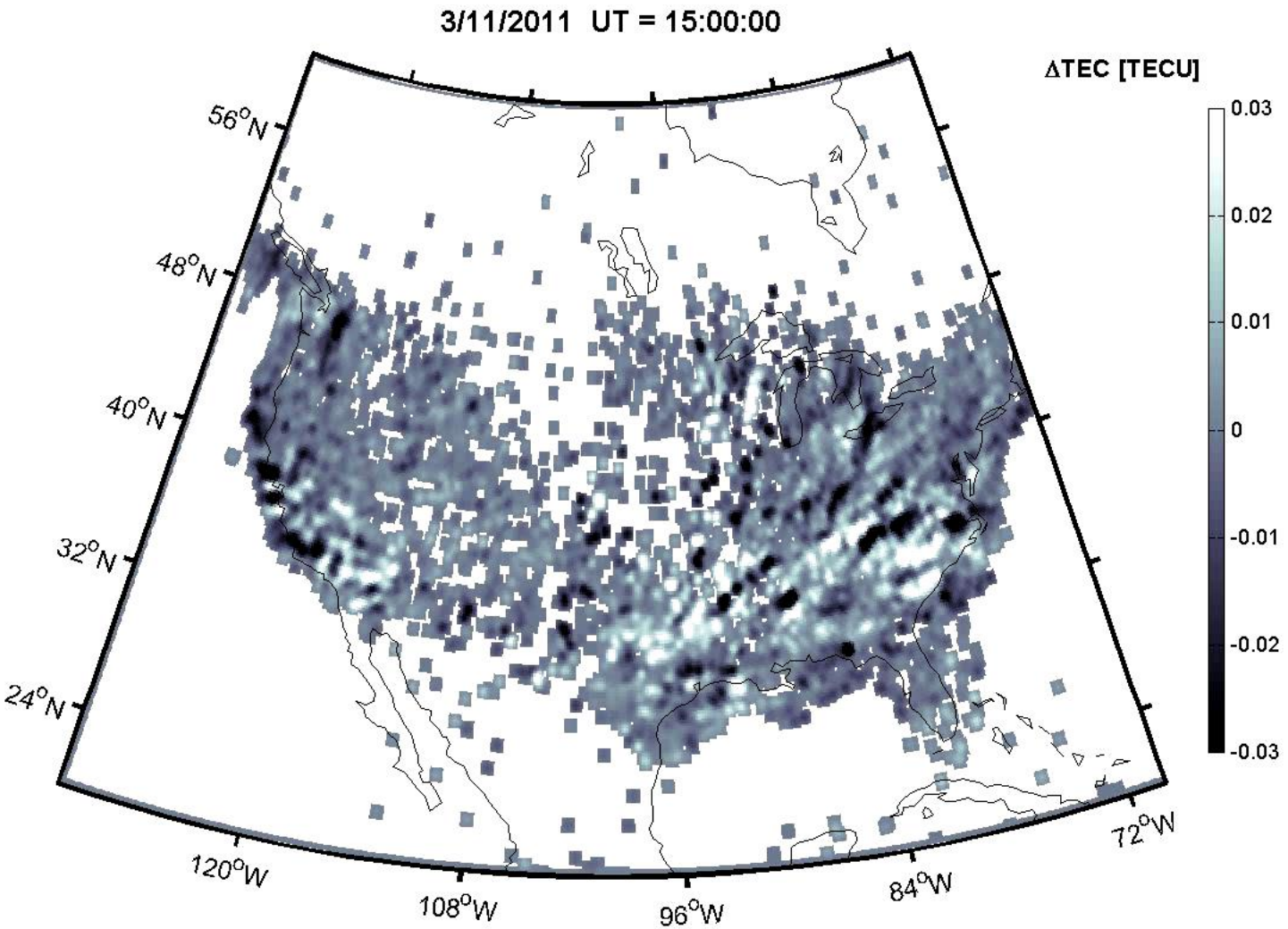






Tsunami **Thunderstorm** **Aurora**

Movie: Tsunami TIDs



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Bringing It All Together

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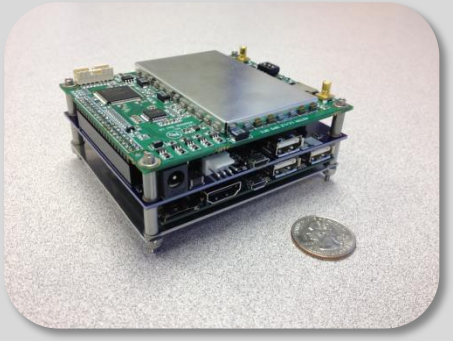
Instrument & Sensor Development



Successful R&D & Tech development

E.g. DoD
SBIR program

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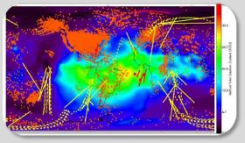
Smallsat Missions

From Design…
…to Final Product

Analysis Tools:

OSSET provides *quantitative impact* relevant to the warfighter…

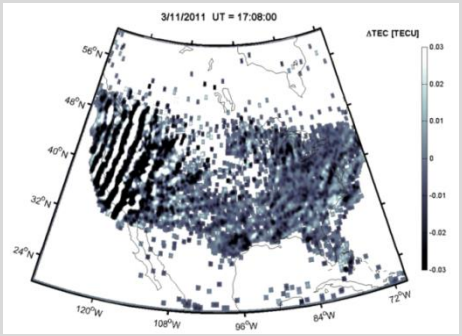


- for effective procurement
- impact of existing and planned sensors

GPS on buoys

…or other moving platform

Data Assimilation GPS Derived TIDs



ASTRA: Overview

❖Science
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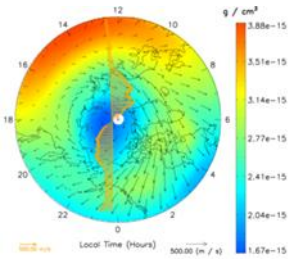
ASTRA

Modeling

Physics-Based Modeling (TIMEGCM)

Real-Time Specification of Ionosphere/ Thermosphere



Celebrating our 11th Anniversary

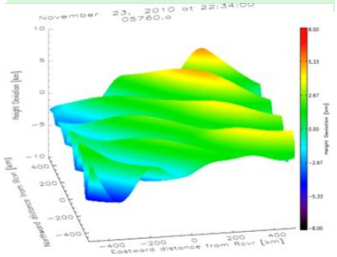
Data Assimilation

High-latitude Electrodynamics

Global Ionosphere

Thermospheric Neutral Density

Satellite Drag & Ballistic Coefficients



Data & Eng. Services

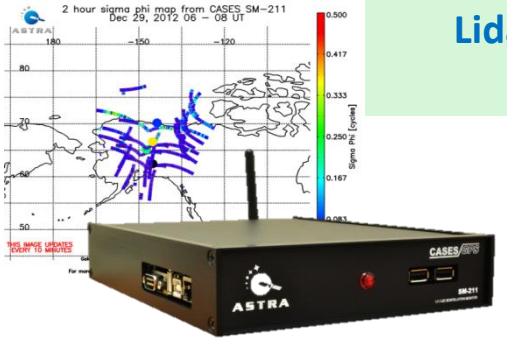
Space Based Data

Ground Based Data

Forensic Space Weather Analysis

Spacecraft Modeling

Systems Engineering



Ground-based Instrument Development

GPS-based Space Weather Monitor

E-fields and Magnetometers

Low Power Ionospheric Sounder

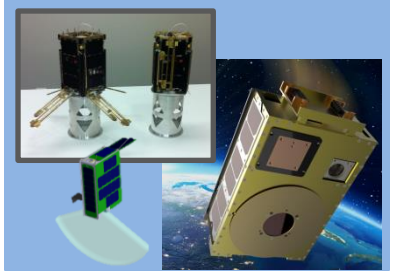
HF TID Mapper

Lidar Systems

COLORADO COMPANIES TO WATCH
2016 WINNER

Space Systems

CubeSat Missions



Plug-N-Play Avionics

CubeSat Instruments

- Scanning UV Photometer
- E-field Double Probe
- RF Waves & Sounder
- Wind Profiler
- GPS-based Space Weather Monitor
- Magnetometer & Langmuir Probe

Hosted Payloads

WAAS: Mitigation of Space Weather

❖Science
❖ Technology
❖ Applications
Bringing It All Together

What is it?

- Air navigation aid developed by FAA
- Augments the GPS system
- Goal: improve accuracy, integrity and availability
- Enable aircraft to rely on GPS for all phases of flight (esp. precision landing)

WAAS Consists of:

- Network of ground-based reference stations
- Measure TEC and compute "Deviation Correction"
- Routes measurements to Master Stations
- Send Deviation Corrections to geostationary WAAS satellites (every 5 sec)
- Satellites broadcast corrections back to earth
- WAAS enabled GPS receivers use corrections while computing their positions to improve accuracy

Accuracy

- Goal: 25 ft or better (Vert and horiz) 95% of time
- Typically: better than 3ft vertically and horiz

DR#52: Ionospheric Scintillation caused High Position Errors at Fairbanks

GPS Week/Day: Week 1420 Day 5 (March 30, 2007)

Discussion: On March 30, 2007 (GPS Week 1420 Day 5), large vertical position errors (VPE) were observed at Fairbanks WAAS reference receiver thread A (WRE-A).